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SEISMIC DATA LABORATORY QUARTERLY TECHNICAL SUMMARY REPORT

16 JANUARY 1967

Prepared for

AIR FORCE TECHNICAL APPLICATIONS CENTER

Washington, D. C.

By

EARTH SCIENCES DIVISION
TELEDYNE INDUSTRIES, INC.

Under

Project VELA UNIFORM

Sponsored By

ADVANCED RESEARCH PROJECTS AGENCY

Nuclear Test Detection Office

ARPA Order No. 624

SEISMIC DATA LABORATORY

QUARTERLY TECHNICAL

SUMMARY REPORT

16 January 1967

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Neither the Advanced Research Projects Agency nor the Air Force Technical Applications Center will be responsible for information contained herein which may have been supplied by other organizations or contractors, and this document is subject to later revision as may be necessary.

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I. INTRODUCTION

This is the seventh quarterly technical summary report issued by SDL and covers the period October through December 1966. Work previously completed or work currently in progress is mentioned only as it relates to analyses completed during this reporting period.

Analyses performed, for which results have been reported are discussed in Section II under descriptive headings. Section III contains a discussion of the support and service tasks performed for in-house projects and for other VELA UNIFORM participants.

Appendix A is a listing of those organizations receiving SDL data services during this period; and Appendix B contains selected SDL reports which are representative of the types of analyses made by the Seismic Data Laboratory.

II. WORK COMPLETED

A. Finite Fourier Transform Theory and Its Application to the Computation of Convolutions, Correlations, and Spectra

Practical and computational aspects of the theory of Fourier Transforms have been examined in connection with various SDL research analyses. These efforts have resulted in a set of programs for performing operations on time series based on the Cooley-Tukey (References 1,2) hyper-rapid Fourier transform method. Using this method, computations on seismic array data such as the calculation of convolutions, correlations, spectra, and digital filters have been speeded up by factors of three or four and sometimes even ten. Following is a brief description of the procedures followed and the results obtained from these procedures.

1. Finite and Discrete Fourier Transforms

In the case of continuous data of infinite length, the Fourier transform pair is the direct transform and the inverse transform. Sometimes the direct transform is written with a factor of 1 in front on the integral and the inverse with a factor of $1/2\pi$. Quantities of interest, such as spectra, etc., involve magnitudes or squares of one transform and the factor must be inserted or taken out, depending on which definition is used, to preserve the proper dimensions.

Two drawbacks of these definitions for digital computations are apparent: First, the integrals must be approximated by sums in the digital computer, which implies that both transforms involve sampled variables. Second, the infinite limits on the sums are impossible in practice. Clearly, these sums must be truncated, as they do not in general converge over a finite interval. As a result, Fourier transforms as such are never really computed by a digital computer. Instead, the complex samples of a direct transform are approximated by the cosine and sine coefficients of Fourier series representation of the input data.

If N samples of the data are taken at equally spaced intervals $\Delta t = T/N$, the integrals become sums, and the frequency sum goes from DC to the folding frequency. It was found that a great deal of symmetry between the two transforms could be preserved if the sum is summed up to N-1. Redundant points in the spectrum are included (since the transforms are periodic) but the computational procedures are simplified.

It was shown that the set of direct Fourier transform points, between DC and the folding frequency, contained the same amount of information as the real data series, which suggested that the existence of one transform should imply the existence of the other.

2. Two-and-Three-Dimensional Fourier Transforms

Two- and three-dimensional direct Fourier transforms are seen to be

$$A(k_1,k_2) = \frac{1}{\sqrt{N_1 N_2}} \sum_{j_1=0}^{N_1-1} \sum_{j_2=0}^{N_2-1} x(j_1,j_2)\, w_1^{-j_1 k_1}\, w_2^{-j_2 k_2} \qquad (1)$$

and

$$A(k_1,k_2,k_3) = \frac{1}{\sqrt{N_1 N_2 N_3}} \sum_{j_1=0}^{N_1-1} \sum_{j_2=0}^{N_2-1} \sum_{j_3=0}^{N_3-1} x(j_1,j_2,j_3)\, w_1^{-j_1 k_1} \cdot$$

$$\cdot w_2^{-j_2 k_2}\, w_3^{-j_3 k_3} \qquad (2)$$

By separating and breaking up these equations, it was calculated that $N_1 + N_2$ one-dimensional transforms are required to compute the single two-dimensional transform, and that $N_1 N_2$ one-dimensional transforms and N_3 two-dimensional transforms are needed to compute the single three-dimensional transform.

3. Speed-Up of Transform Computing Time

It was shown that the process of transforming is equivalent to matrix multiplication by a matrix W, which preserves "length" between two domains. The Cooley-Tukey method factors the W matrix, if its order is a power of two, into L + 1 sparse matrices, where L is the power of two. Multiplying L + 1 times by these sparse matrices can in some cases reduce the computing time by many tens of times.

4. High-Speed Correlations and Convolutions

By computing Fourier transforms with a finite Fourier series-like method an important condition is put on the time series. As in regular Fourier series the input is assumed to be periodic with period T and the integrals or sums are computed over a single period. There is also the effect of cutting off the spectrum at the folding frequency. Sines and cosines of finite wavelength will repeat again outside the region of interest. This fact in itself is not bothersome but becomes a serious complication in the computation of convolutions and correlations. Convolutions and correlations as usually computed assume the time series to be zero outside the region of interest. Therefore, the integrals or sums in computing them are summed out only over the non-zero terms. When multiplying together two finite Fourier transforms (or the complex conjugate of one times the other) the periodicity of the time series means that elements which have been shifted past the end of a period reappear at the beginning. This process is called circular convolution or correlation and its effects are unavoidable when straightforwardly computing lagged products with finite Fourier transforms.

Circular convolution is written:

$$R_{ij}^{c}(t) = \sum_{\tau=0}^{T-1} x_i(\tau)\, x_j(t+\tau) \qquad (3)$$

where $x_m(t + T) = x_m(t)$ for all m.

It was shown that this kind of correlation is equal to the transform of the absolute product of the two finite transforms.

On the other hand the transient correlation for positive lags is defined by the following:

$$R^T_{ij}(t) = \sum_{\tau=0}^{T-1-t} x_i(\tau)\, x_j(t+\tau) \qquad (4)$$

where the upper limit on the sum simulates the desired zeros in the time series outside the region of interest. The finite Fourier transform of this R^T is thus not the product of the two individual transforms. However, by filling zeros into the second half of each data series and computing their transforms out to twice their actual length, a good estimate of the spectrum may be obtained. In addition, the negative lags in the correlation appear, thus giving a more mathematically satisfying result.

Transient correlations for 100% lags were shown to be computed by forming the absolute product of two transforms, each computed out to twice the length of the original data series with zeros filled into the second halves.

Non-circular or transient convolutions were also computed in much the same way, except that the transforms had to be computed out to a length equal to the sum of the lengths of the time series and the filter, with the appropriate number of zeros filled into each. The convolution theorem was proved in the same fashion and were computed by forming the product of the two transforms, each computed out to a length equal to their sum with zeros filled into the extra lengths.

B. Rayleigh Wave Rejection by Optimum Filtering of Vertical Arrays

Vertical arrays offer some intriguing advantages over other arrangements of seismometers. Assuming the noise to be composed of Rayleigh waves and perhaps some mantle-propagating P-waves, and assuming the signals to be teleseismic P-waves, the noise and signals will be recorded by a vertical array with some rather special characteristics.

We can imagine that each mode of Rayleigh wave noise possesses a random character common to noise functions in general. However, for each Rayleigh wave mode the response versus depth and frequency relative to its response on the surface is predictable. Because the relative depth variation is predictable, the vertical array can be summed to cancel the Rayleigh modes. In contrast, the noise over a surface array is more unpredictable and more variable and, therefore, more difficult to cancel by array summation.

The purpose of this analysis was to test the theory of applying maximum likelihood filters in vertical arrays in order to provide undistorted estimates of the signal or the various Rayleigh modes with the other modes cancelled out.

A vertical array of five vertical component seismometers which existed in a well at the Uinta Basin Seismological Observatory (UBSO) was used for testing this theory. The Rayleigh dispersion curves for this well indicated that the fundamental, first, and second higher Rayleigh modes would all be supported over the signal frequency range of 0.5 to 2.0 cps. Since we wanted more recording levels than modes, these three Rayleigh modes plus a signal mode were the only ones considered to exist in our synthetic modeling of this well.

The optimum filter, G, solutions are the least squares inverse to the Rayleigh signal filter matrix, H. Thus, the matrix products of G and H gives the identity matrix. In our test model we assumed the signal existed with the same size and amplitude on all traces. We derived optimum filter solutions only over the signal range of 0.5 to 2.0 cps. For the frequencies below 0.5, we smoothed the frequency responses to zero according to a sinusoidal gain function for both the H and G frequency responses. We smoothed these responses to zero in a similar way over the range from 2 to 5 cps. Also, the orthogonality of our optimum filter solutions were maintained over the entire frequency range.

In order to demonstrate that our optimum filter solutions were correct, we created some synthetic data which conformed to the well log analysis we assumed for the UBO well. These Rayleigh mode traces were combined with an artificial signal to produce a mixture of signal and Rayleigh modes expected from this well.

Figure 1 shows the data from the five levels of the vertical array if the signal plus the fundamental and the first and second higher Rayleigh modes have been added into the vertical array data. The outputs for the signal and the three Rayleigh modes are reproduced in size and waveform within a few percent of the expected results. The signal trace shows better than a 20 db improvement over the best signal/noise ratio available in the vertical array. Thus, the optimum filters perform as expected when the data properties match the dispersion analysis of the well log.

These solutions were then applied to actual noise data recorded at the vertical array. All of the optimum filters used required inputs from all five levels of noise data. However, we

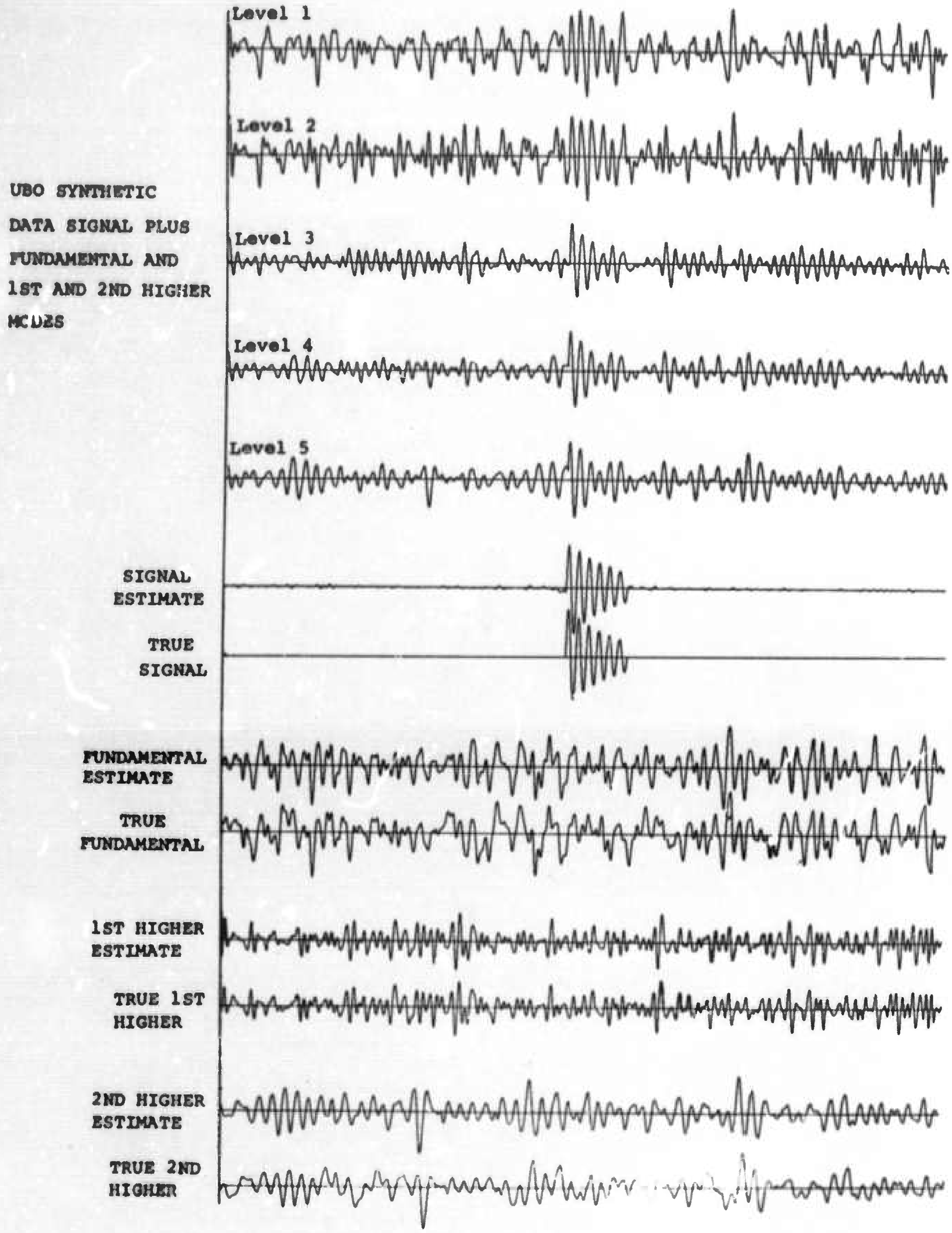


Figure 1. Optimum Filters Estimating Four Modes (The Signal and Three Rayleigh Modes) from Synthetic Data with all Four Modes Present.

could ask for estimates of only a single mode or for estimates of several modes in the filter outputs. The more modes a set of filters estimate, the larger the filter gains will be. It follows that any errors resulting from incorrect dispersion analysis, instrument calibrations, or non-parallel layering will be amplified much more in these filters with fewer degrees of freedom. Results showed that the signal estimate outputs gave progressively increasing low frequency errors on the estimates of all modes as the degrees of freedom decreased (i.e., as the number of outputs increased).

It was concluded that our optimum filter solutions have the following features:

1. These filters are indeed orthogonal and separate the noise and signal modes as planned.

2. These optimum filters extend for 400 points in time since the frequency interval chosen was 0.5 cps.

3. The gain on the synthetic examples was greater than 20db with solutions restricted to the 0.5 - 2.0 frequency range. More resolution in frequency could increase this figure.

4. The optimum filters are zero phase shift filters. Therefore, they are algebraically additive.

5. The optimum filters become larger in gains (both positive and negative) as degrees of freedom decrease.

6. The optimum filters become larger in gains (both positive and negative) as the aperture of array goes down. Thus, for low frequencies the solutions tend to become unstable.

7. Extra modes not considered and errors in assumptions cause errors in the output. Errors in assumptions can include an incorrect well log, non-parallel layering in surrounding medium, and incorrect calibrations of seismometers.

8. Extra degrees of freedom are needed to cut gains of optimum filters and make optimum solutions more tolerant of errors.

9. Extra degrees of freedom are best obtained by increasing the number of seismometers in the vertical array.

10. More stable solutions (i.e., optimum filters with lower gain) will be obtained rrom the deeper vertical arrays which have the seismometers distributed rather uniformly throughout the array.

C. LASA Travel-Time Data at the SDL

In connection with its many LASA analyses, the SDL is accumulating relative travel-times at the Montana Large Aperture Seismic Array (LASA) with a view towards computing travel-time anomalies at the 21 subarrays. In the belief that these raw data are in demand and may be of use to the seismic community in general, a report was issued which contains LASA travel-time data for approximately 400 events, as read from LASA films.

Figure 2 shows the type of data which has been computed and the following numbered explanation, corresponding to the circled number on the figure, describes the method of presentation:

1. Arbitrary region name
2. Direction of approach
3. Distance range for events included in region
4. Azimuth range for events included in region
5. Event date and name
6. PDE latitude
7. PDE longitude
8. PDE depth
9. PDE origin time

11 22 66 (2) (3) PAGE 1

(1) CENTRAL AND SOUTHERN ALASKA (6) (7) NW (8) 2850 = 3390 KM 313-327AZ (4)

(5) 19 AUG66 GULF ALASKA		59 50 00. N	143 30 00. W		033.	03 10 04.2 (9)	
(10) 37.11	37.58	36.54	36.27	36.44	38.01	37.47	0310 (11)
35.75	37.54	39.00	36.40	34.55	34.55	41.90	
39.60	31.06	37.13	44.00	37.41	28.95	38.87	
15 AUG66 SO ALASKA 1		60 24 00. N	146 00 00. W		09.	13 36 23.7	
0.	0.	0.	0.	0.	0.	0.	1341
0.	0.	0.	0.	0.	0.	0.	
49.22	62.79	60.51	74.41	67.10	55.50	66.42	
02 SEP66 SO ALASKA		60 12 00. N	140 54 00. W		031.	22 46 39.5	
23.53	23.41	22.95	22.05	22.05	24.42	23.84	2252
0.	23.90	25.36	22.09	21.01	0.	28.14	
0.	19.51	23.34	31.15	23.90	15.41	23.23	
09 APR66 SO. ALASKA		60 12 0. N	147 00 0. W		34.	18 51 45.0	
29.74	29.18	28.10	27.00	27.90	29.00	29.00	1857
27.40	29.08	30.57	20.03	20.10	0.	33.38	
31.40	29.03	28.79	30.20	29.19	0.	28.44	
06 NOV65 S ALASKA		60 30 0. N	147 18 0. W		37.	06 38 41.5	
0.	0.	0.	27.00	27.12	0.	28.23	0644
26.60	28.25	29.78	27.39	25.30	0.	0.	
0.	23.97	27.78	35.00	0.	19.70	27.60	
30 AUG66 SO ALASKA		61 18 00. N	147 30 00. W		036.	20 20 54.0	
41.82	42.13	41.29	40.04	0.	42.51	41.98	2020
40.48	41.92	43.50	41.19	39.15	38.00	46.11	
44.40	37.98	41.35	44.50	42.57	33.50	41.49	
22 JUN66 S. ALASKA		61 24 00. N	147 42 00. W		053.	11 36 53.7	
0.	0.	38.95	34.70	38.03	40.40	39.90	1144
38.32	39.72	41.40	39.00	37.00	36.70	43.90	
42.31	35.73	39.27	47.30	40.34	31.38	39.27	
01 SEP66 SO ALASKA		61 48 00. N	149 36 00. W		077.	23 19 09.8	
63.30	63.77	62.08	62.40	62.54	64.17	63.70	2324
62.11	63.51	0.	62.70	0.	60.50	67.91	
70.04	59.01	67.97	70.90	64.15	55.15	63.12	
15 AUG66 SO ALASKA 2		61 12 00. N	150 00 00. W		98.	19 37 16.0	
70.20	63.77	0.	67.47	67.50	69.18	0.	1947
67.03	66.54	69.98	0.	65.02	0.	0.	
0.	64.28	0.	75.74	0.	60.14	66.02	
24 NOV65 C ALASKA		63 12 0. N	151 00 0. W		129.	08 22 38.7	
33.40	33.00	0.	32.55	32.05	34.20	33.85	0820
32.20	33.60	35.20	32.95	30.05	30.60	37.75	
0.	27.08	32.70	41.20	34.05	0.	33.20	
22 MAR66 SO. ALASKA		61 00 0. N	152 00 0. W		100.	10 24 59.0	
58.22	55.58	57.01	57.40	57.51	59.11	58.50	1034
50.99	56.00	60.08	57.03	55.00	0.	0.	
0.	0.	0.	0.	0.	0.	55.00	
06 FEB66 S. ALASKA		60 24 00. N	152 10 00. W		91.	23 28 07.8	
68.97	69.32	68.45	68.13	68.10	69.00	69.23	2333
67.80	67.36	70.75	65.30	65.40	66.40	73.48	
71.32	61.95	67.09	75.41	69.43	60.99	68.65	

Figure 2. Type of LASA Travel-Time Data Computed by the SDL

10. Arrival time in seconds (an arrival time of "0" indicated no reading made at that subarray.

First row, left to right: B1, B2, B3, B4, C1, C2, C3

Second row : C4, D1, D2, D3, D4, E1, E2

Third row : E3, E4, F1, F2, F3, F4, A0

11. Arrival time, hour and minute at LASA

D. Energy Fluctuations in Seismic Noise

In recent years, statistical methods have been successfully used to predict the change in ambient seismic noise power sensed by burying a seismometer beneath the surface of the earth. Observations of seismic noise has indicated a large standing wave or isotropic component composed of the admixture of many propagation modes. Statistical theories such as equipartition of energy have been reasonably successful for deriving the excitation of the propagation modes.

Since such models are classically described by waves from a zero-mean Gaussian population, the purpose of this study was to tentatively assume that the seismic noise is Gaussian and to try to reject the hypothesis by measuring the relative frequency of occurrence of specific particle energies sequentially observed on samples of seismic noise. As control for the study, the same frequency of occurrence observations were made of a thermal noise sample recorded on tape from a Gaussian noise generator. The energy envelope of Gaussian noise is theoretically described by a Boltzman or exponential probability function, thus the fit of a straight line to the log of the relative frequency of occurrence is a test of the Gaussian hypothesis. Two tests were used; one was the chi-square test of the deviation from the least squares straight line; the other, more powerful

test, compared the variance of the seismic noise and that of the Gaussian noise generator.

Three hours of seismic noise was selected which appeared to be typical of the normal ambient background. The noise was measured at a depth of 7,452 feet in a deepwell near Apache, Oklahoma. The near surface layering is described as high velocity limestones of approximately 6 km/sec overlying an igneous basement complex of velocities in the neighborhood of 5 km/sec.

As shown on Figure 3 for seismic noise, the relative frequency of occurrence is given by the vertical axis, and the class interval in order of increasing energy is shown on the horizontal axis. On each plot, the center frequency and effective bandwidth of the filter is labeled. On Figure 4, the same information is shown for the Gaussian noise generator. Comparing Figure 3 with Figure 4, the scatter from a linear trend is the same overall for both sets of data, seismic and Gaussian generator.

Based on the chi-square test, it is more than 99% probable that samples at all of the frequencies are from a zero mean Gaussian population. The hypothesis that the class deviation of the seismic noise sample and the thermal noise sample are from the same random population is rejected only for the sample at 1.4 cps, suggesting that a non-Gaussian component may be included with the noise in this band. If we accept the Gaussian hypothesis, theoretical interest in the power spectral density of the noise may bear ultimately on dissipation mechanisms and may possibly lead to analysis of geological structure, with the real changes in the power spectrum in a region depending primarily on changes in structure. Of more practical interest is that modern literature on detection and filtering is most meaningful in the context of seismic signals added to Gaussian noise.

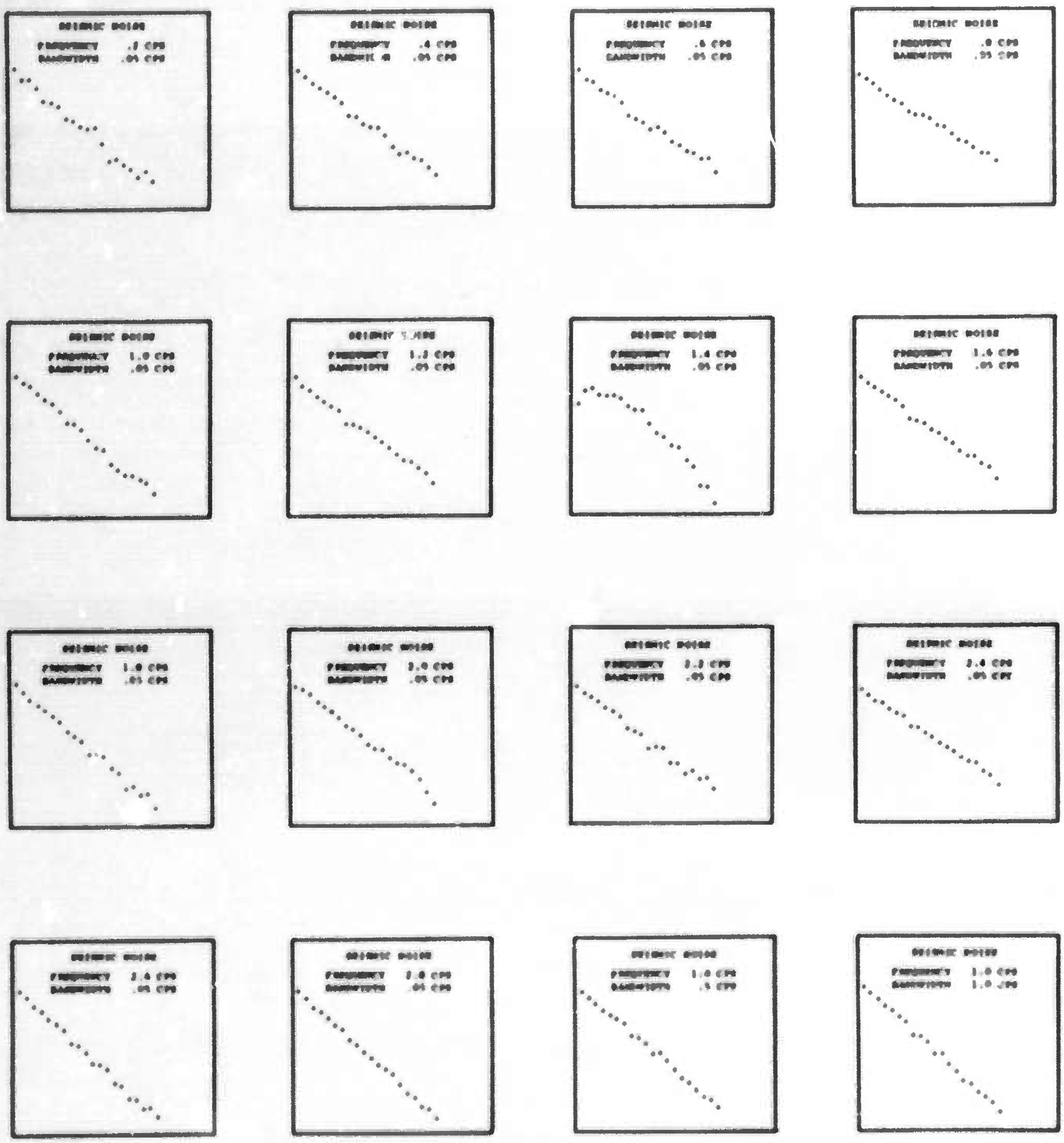


Figure 3. Relative Frequency of Occurrence (Ordinate) Versus Energy Level (Abscissa)

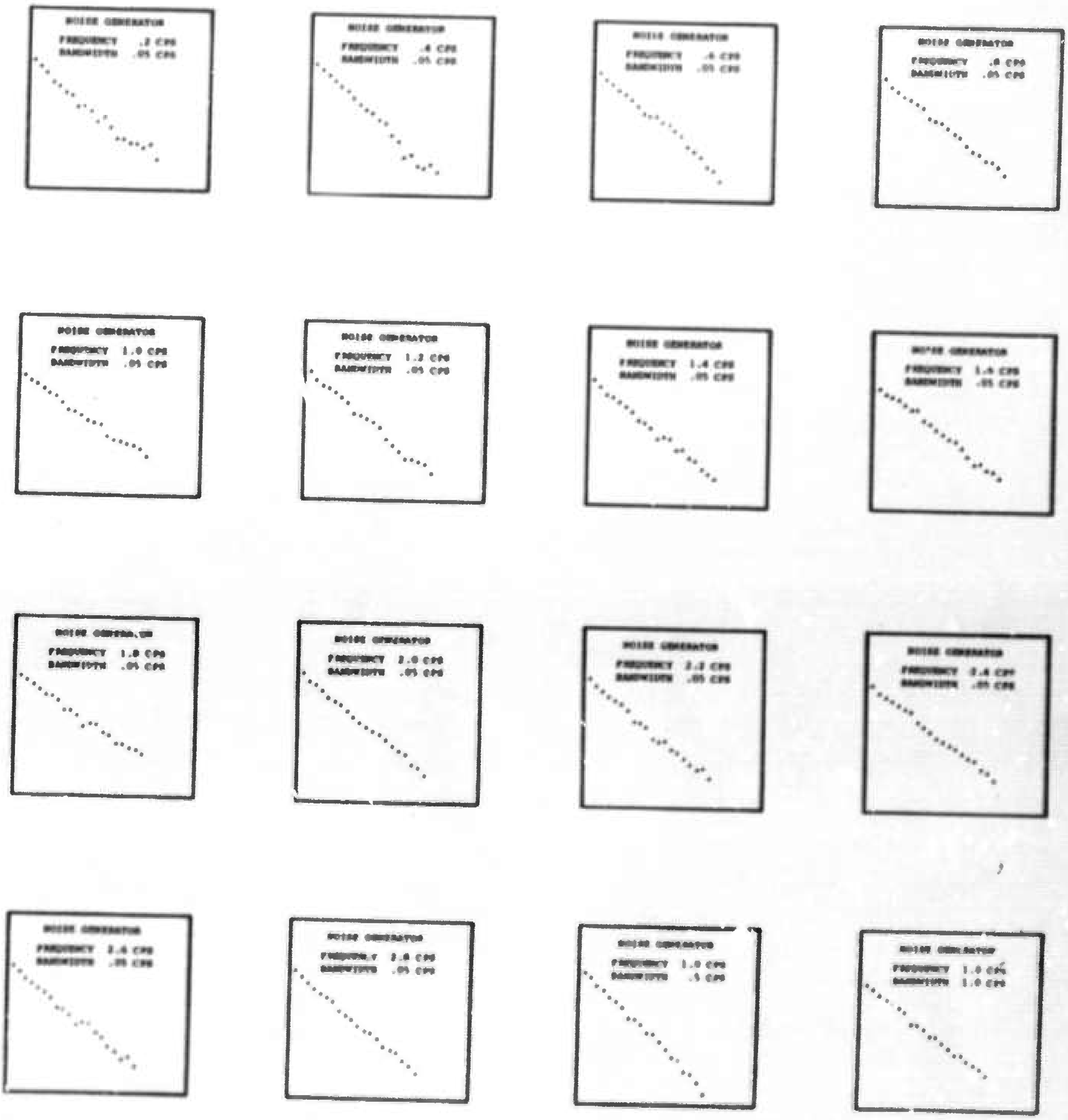


Figure 4. Relative Frequency of Occurrence (Ordinate) Versus Energy Level (Abscissa)

E. Shot and Earthquake Analyses

Standard statistical summary reports were issued on the Nevada Test Site (NTS) events TAN and HALF BEAK. TAN, detonated on 3 June 1966 in a tuff geologic medium, had an average magnitude of 5.56 ± 0.49; short-period signals were recorded by 22 stations and long-period signals were recorded by 21 stations. HALF BEAK, detonated on 30 June 1966 in a rhyolite geologic medium, had an average magnitude of 6.02 ± 0.60, with short-period and long-period signals being recorded by 21 and 20 stations, respectively. Figure 5, showing the Lg amplitudes for TAN and HALF BEAK, are illustrative of the statistics summarized from these analyses.

Other projects completed included the following:

- signal albums (photographic enlargements of the 16 mm and 35 mm film records for the LRSM and observatory stations) from 5 events.
- analysis of 575 events for a special long-period study
- film analysis of CPSO noise
- special LASA PcP study

F. Vertical Array Teleseismic Signal Measurements

The concept of a vertical array is to record simultaneously on several transducers stacked in a deepwell 3 km or more in depth. The purpose of this study was to investigate the possibility of reducing near surface reverberations due to geological effects near the vertical array receivers, based on procedures established over a period of time in reflection seismology, where vertical stacking of an explosion source is used to remove distortion of near surface layering, mainly the ghost reflection from the surface. By reciprocity, the same algorithms developed for stacked sources can be applied to stacked receivers by reversing the sign of the reflection coefficients.

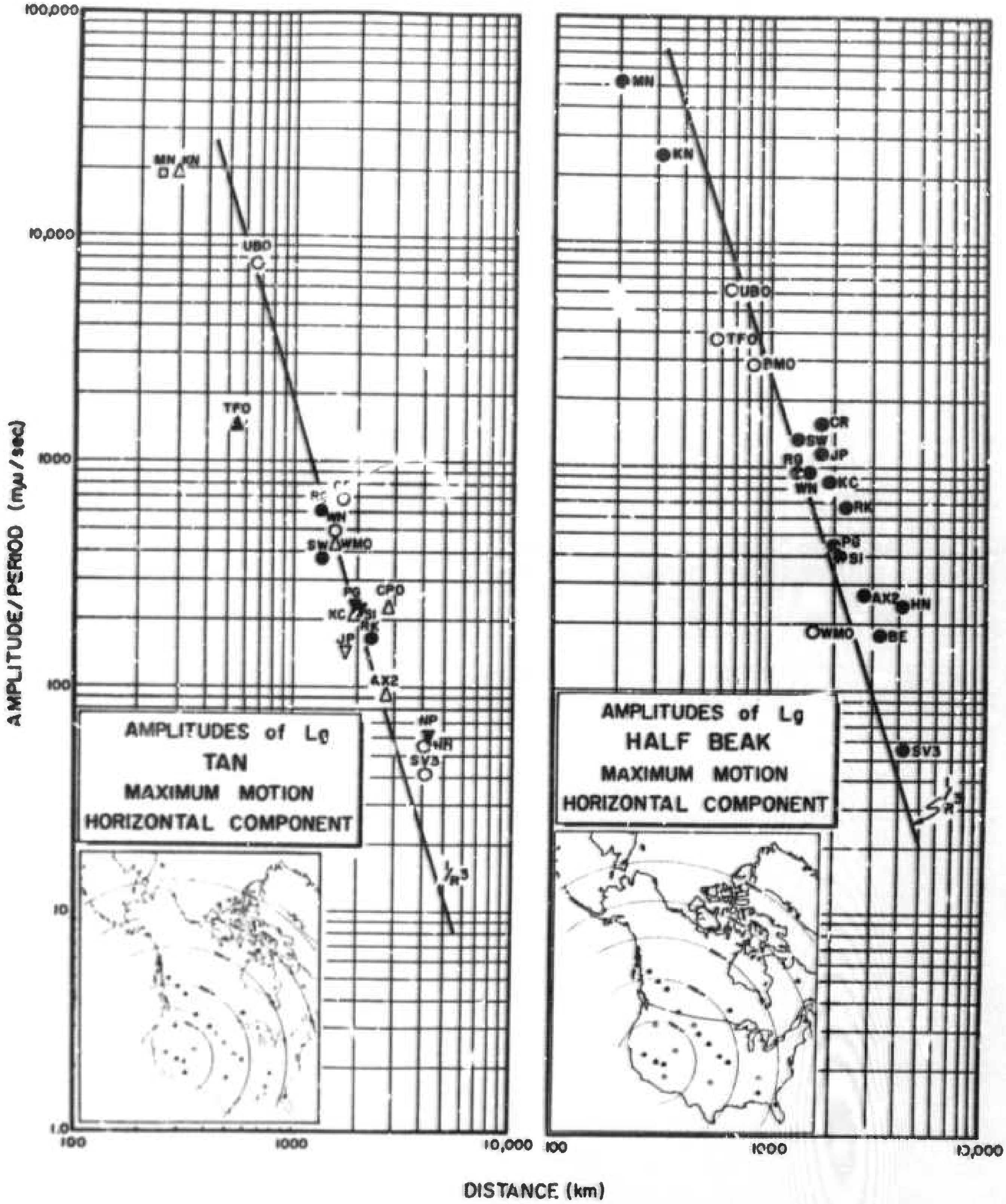


Figure 5. Lg Amplitudes for Two NTS Nuclear Explosions

The data used were three events recorded at a deepwell, each having different focal depths and different apparent frequencies.

Before developing the deghosting technique, the deepwell trace was simulated from a surface seismogram. If a deepwell trace can be simulated by adding only an echo from the surface, it seems entirely plausible that by removing the ghost reflection from the deepwell trace, the up-going P-pulses can be made to appear similar at each depth.

Two deghosting techniques were developed as follows:

1. When a surface or near surface trace is available, the deghosted trace can be constructed by simply shifting the surface trace by K, multiplying a $\frac{1}{2}\alpha$, and subtracting this resultant from either the deepwell trace (phased vertical array) or the deepwell trace shifted by K/2 (non-phased vertical array).

2. It would seem more plausible to develop a deghosting process that removes the echo without the use of a surface seismogram, a practical technique that would figuratively push the ghost off the end of the deepwell trace.

Given the reflection coefficient α, and the deepwell trace $Y_{i,1}$ the phased deghosted trace is formed as follows: First a new trace $Z_{i,1}$ is defined to be

$$Z_{i,1} = Y_{i,1} - X_{(i - NT_1)} \cdot \alpha_1,$$

where NT_1 is equal to the product of the sampling rate and the echo time delay (K). This above equation simply shifts and inverts the ghost to a point NT_1 farther down the seismic record than it originally was. This iterative process is continued until the ghost reflection is pushed off the seismic record.

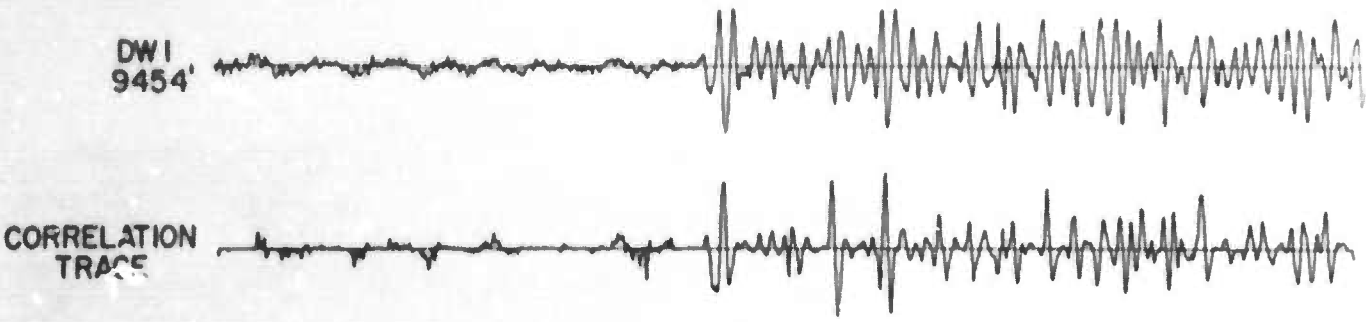
Results tended to show that vertical array processing, based on previous experience with stacked sources, appears to be an effective means of reducing the reverberations and complexity of the coda caused by near surface reverberations at the receiver. In Figure 6, the first two traces show the raw data measurements and its correlation traces, the next two traces show the phased deepwell measurements deghosted by subtraction of the surface measurement, and the last two traces show the phased deepwell measurements deghosted by means of an inverse operator which removes the surface echo. Both deghosting methods performed adequately. The correlation trace for the inverse operation had a slightly cleaner coda and this method has the advantage of not requiring a quiet surface trace and exact control of instrument gain. The correlation traces used for detecting the upgoing P-pulses impose the strongest possible requirement that the signal be fixed jointly on all channels.

III. SUPPORT AND SERVICE TASKS

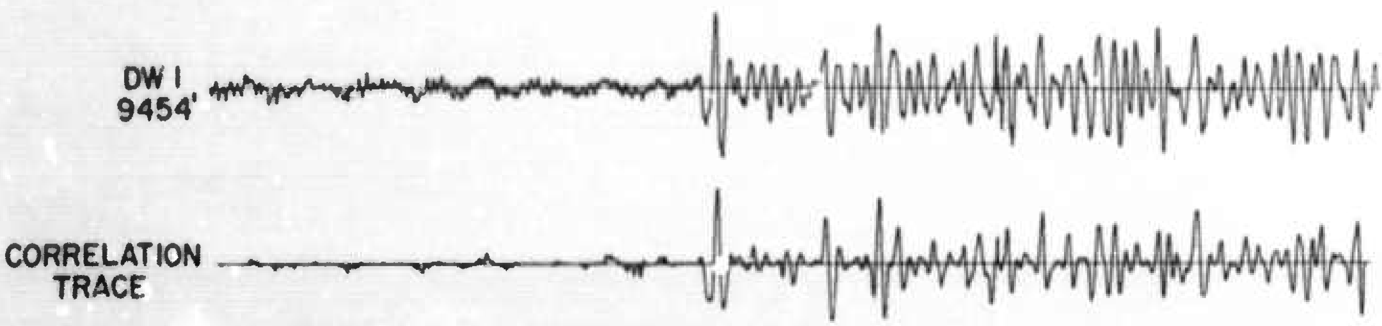
A. VELA UNIFORM Data Services

As part of the contract work-statement, the SDL provided one or more of the following support and service functions for VSC and other VELA participants:

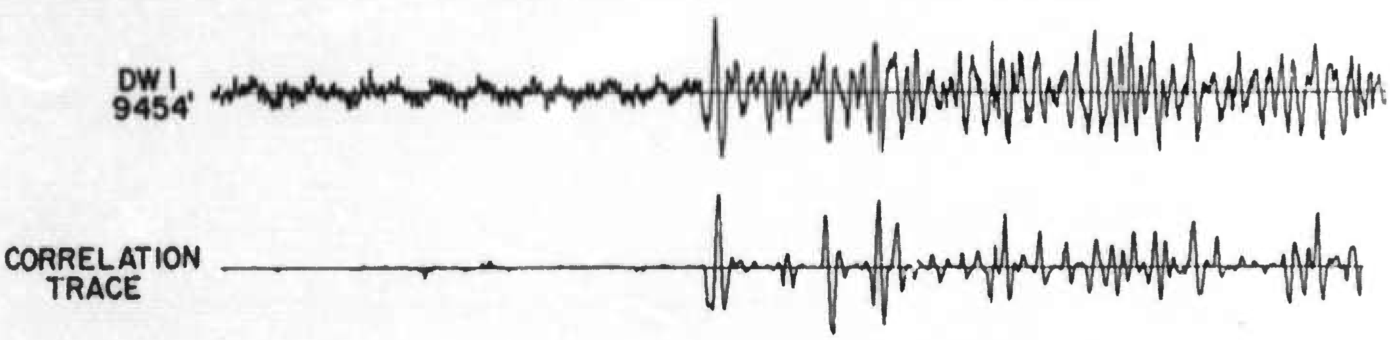
- copies of 16 and 35 mm film
- playouts of earthquakes and special events
- copies of existing composite analog tapes
- composite analog tapes of special events
- use of 1604 computer for checking out new programs or running production programs
- copies of digital programs
- digitized data in standard formats or special formats for use on computers other than the 1604



Original Data



Deghosted by Subtracting Surface Measurement



Deghosted by Invers   erator

Figure 6. Deghosting Techniques for Reducing
Near Surface Reverberations

- running SDL production programs, such as power spectral density and array processing, on specified data
- digital x-y plots of power spectra or digitized data
- signal reproduction booklets
- copies of MIT Geophysics Program Set II
- space for visiting scientists utilizing SDL facilities to study data and exchange information with SDL personnel.

During this report period, 80 such projects, including those for the VELA Seismological Center, were completed and the 18 organizations receiving these services are listed in Appendix B.

B. Data Library

The Data Library contains approximately 7,484 digitized seismograms, 165 digital computer programs and 296 composite analog magnetic tapes, all available for use by the VELA UNIFORM program.

The following additions were made during this report period:

1. Digital Seismograms - 750 including
   - 8 earthquakes recorded at one station
   - 2 earthquakes recorded at 24 stations
   - 6 earthquakes recorded at 85 stations
   - long period data from 7 earthquakes

2. LASA Data - 180 digital tapes and 210 16mm films
   - there are a total of 703 LASA digital tapes and 854 16mm films in the library. There is also a master calibration tape which contains the magnification (digital counts per millicron) of each sensor for every subarray. These magnifications have been computed for all calibration tapes currently in-house. As each new calibration is received, it is routinely run through the program CALIBR and added to the master tape.

3. Digital Programs - 15 including:

SVARRAY - To process vertical array data aligned for first P-motion.

FASTFIL - To broadband pass filter seismograms.

GOSTSEIS- To process vertical array data. This package removes ghost reflection, forms two sum traces - one the deepwell, the other the deghosted deepwell and computes a recursive correlation trace using the deghosted deepwell data. Plots are obtained of each deepwell and deghosted deepwell seismogram, the surface trace, the two above sum traces and the correlation trace.

DEGSEIS - To deghost vertical array seismograms given an echo-time and reflection coefficient for each seismogram. In addition, a sum trace of the deepwell traces, and a sum trace of the aligned-deghosted-deepwell traces are computed. Also, the component which is jointly correlated on all aligned-deghosted-deepwell traces is computed. Furthermore, this program plots all deepwell and deghosted deepwell traces, the pair of sum traces, and the correlation trace.

SGOSTSEI - Ibid "Vertical Array Processor Package I but uses subroutine SDEGOSTE instead of DEGOSTE.

SDEGSEI - To remove ghost reflection on vertical array seismograms aligned for first P-motion, given only the echo-times and reflection coefficients. In addition, sum traces of both the aligned deepwell and aligned-deghosted-deepwell traces are computed. Also, the component which is jointly correlated on all deghosted seismograms is computed. Furthermore, plots are obtained of all deepwell and deghosted deepwell traces, the surface trace, the two above sum traces, and the correlation trace.

VARRAY - To process vertical array data.

RESPONSE - To calculate and plot in k-space the response of an array of seismometers with respect to the response of the

same array to waves with infinite phase velocity (i.e., number of db down from zero).

ABML - To find the maximum absolute value of a fixed or floating point number in an array and the FORTRAN subscript of the array element.

ROOTMNSQ - Using standard library seismogram tapes and LASA calibration tapes, this program will compute the mean over any portion of any channel for a particular seismogram, demagnify, filter or not filter (SDL and L/L coefficients available), and then compute the RMS value over any length of the channel desired.

RECFIL3 - To perform one-pass shift recursive filtering of seismic data given the Q-value, center frequency, and sampling rate.

REVERSE - To time reverse or flip seismic data.

COLYTUKY - To compute Auto-spectra, Cross-spectra, Auto-correlations and Cross-correlations by using the COOLEY-TUKEY method.

CNTUR4 - Writes printer plot of the contours of a two-dimensional array. The contours are formed by shading the area between level 2I and level 2I + 1. This display is superimposed upon either a grid work or a border with tick-marks. The contour levels may be specified individually, or by the increment between levels. In addition, provision has been made to allow the orientation of the array to be altered by either exchanging the rows and columns or reversing either the rows or the columns.

GRTZEL - To compute the Fourier series expansion of a real-valued even function, or the real-valued even function of a real-valued Fourier series expansion.

4. Analog composite Tapes - 13 including:

a. Made by SDL

- 9 special composites

b. Made by Geotech

- DUMONT
- HALF BEAK
- PILE DRIVER
- TAN

C. Data Compression

This is a continuing routine operation, and production is maintained at the level needed to meet the requirements of the field operation (LRSM and U.S. Observatories) and the Seismic Data Laboratory. For this period, 3,767 tapes were compressed.

D. Equipment Modifications

The A/D system has been modified so that the digitizing rate can be synchronized to VELA Time Code, thus minimizing speed differences between analog recordings from different stations.

The Pace 231-R analog computer has been modified to provide additional gain input to each amplifier so that both do not have to be utilized when increasing gain.

E. Automated Bulletin Process

July and August 1966 LRSM and Observatory bulletins were processed during this report period and forwarded to the Geotech Division, Teledyne Industries, Inc., for checking and publication.

F. Special Data Processing

A 1604 program has been written to put the LASA slow mode data tapes into the SDL library format. Either the short period center instrument data or the long period three component data can be processed.

A 160-A program has been written for D to A conversion of the LASA slow mode tapes. Thus DAC playouts can be made directly from the 800 bpi LASA field tapes.

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APPENDIX A

ORGANIZATIONS RECEIVING SDL DATA SERVICES

October 1966 - December 1966

Brown Engineering, Incorporated

Canadian Pacific Oil and Gas Company
Continental Oil Company

Earth Sciences Division, Teledyne, Inc.

General Atronics Corporation
Geotech Division, Teledyne, Inc.
Graduate Research Center of the Southwest

Massachusetts Institute of Technology
Mitre Corporation

Oregon State University

Penn State University
Princeton University

Rome Air Force Base

St. Louis University

Texas Instruments, Incorporated

University of Tasmania
U. S. Coast and Geodetic Survey

Vitro Corporation

APPENDIX B

SELECTED SDL REPORTS

Archambeau, C. B., Flinn, E. A.; Detection, Analysis and Interpretation of the Teleseismic Signal from the SALMON Event; 2 April 1965

Archambeau, C. B., Flinn, E. A.; Perturbation Theory for the Inversion of Body Wave Travel-Time Data; 5 April 1966

Booker, A. H.; Estimation of Network Capability; 20 January 1964

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Bradford, J. C.; Evaluation of the TFSO 31 Element Array; 13 December 1963

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[1]Measurement Analysis Corporation

Chiburis, E. F.; Hartenberger, R.A.: Signal-To-Noise Ratio Improvement by Time-Shifting and Summing LASA Seismograms; 30 September 1966

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Flinn, E. A.; Confidence Regions and Error Determination for Seismic Event Location; 24 April 1964

Flinn, E. A.; Hartenberger, R. A.; and McCowan, D. W.; An Example of Maximum-Likelihood Filtering of LASA Seismograms; 14 March 1966

Flinn, E. A.; Hartenberger, R. A.; and McCowan, D. W.; Two Examples of Maximum-Likelihood Filtering of LASA Seismograms; 8 June 1966

Flinn, E. A.; Hartenberger, R. A.; and McCowan, D. W.; Maximum-Likelihood Filtering of LASA Noise Seismograms; 8 June 1966

[1]Measurement Analysis Corp.

[2]Westat Research, Inc.

[3]U.S. Coast & Geodetic Survey

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Griffin, J. N.; REMODE Signal/Noise Tests in Polarized Noise; 16 September 1966

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Martinek, J.; Thielman, H. P.; A Circle Theorem Related to a Plate in Pure Bending with a Sliding Clamped Edge (Interior Problem); 27 November 1963

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[4] VSC

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[4]VSC

[5]Geotech Division

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13. ABSTRACT

This report discusses the work performed by SDL for the period October through December 1966, and is primarily concerned with seismic research activities leading to the detection and identification of nuclear explosions as distinguished from earthquake phenomenon. Also discussed are the data services performed for other participants in the VELA UNIFORM project.

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Seismic Data Analysis						
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